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AN EXPLORATORY RESEARCH AND DEVELOPMENT PROGRAM LEADING TO SPEC--ETC(U)

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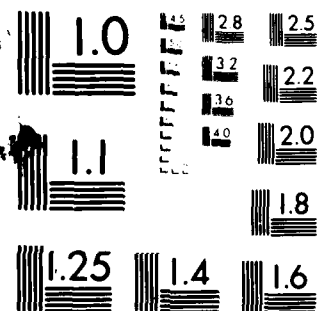
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AN EXPLORATORY RESEARCH AND DEVELOPMENT PROGRAM
LEADING TO SPECIFICATIONS FOR AVIATION TURBINE
FUEL FROM WHOLE CRUDE SHALE OIL

Part I. Preliminary Process Analyses



AD A112681

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<table border="0"> <tr> <td>Shale oil</td> <td>Hydrocracking</td> <td>Jet Fuel Specifications</td> </tr> <tr> <td>Paraho Shale Oil</td> <td>Hydrorefining</td> <td>Processing Schemes</td> </tr> <tr> <td>Occidental Shale Oil</td> <td>Hydrogen Chloride Treatment</td> <td>Investment Costs</td> </tr> <tr> <td>JP-4 Jet Fuel</td> <td>Solvent Extraction</td> <td>Operating Costs</td> </tr> <tr> <td>JP-8 Jet Fuel</td> <td>Dimethylformamide</td> <td>Product Costs</td> </tr> </table>			Shale oil	Hydrocracking	Jet Fuel Specifications	Paraho Shale Oil	Hydrorefining	Processing Schemes	Occidental Shale Oil	Hydrogen Chloride Treatment	Investment Costs	JP-4 Jet Fuel	Solvent Extraction	Operating Costs	JP-8 Jet Fuel	Dimethylformamide	Product Costs
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number) Part I - Preliminary process analyses of three different technically feasible processing schemes proposed by SUN TECH, INC. for converting 100,000 BPCD of raw Paraho shale oil into military turbine fuels was investigated. Each processing scheme is based on very limited, but pertinent, data generated by SUN TECH plus literature sources. The base processing scheme consists of severe hydrotreating followed by sulfuric acid extraction; the two alternate cases utilize moderate hydrotreating plus extraction for nitrogen removal and hydrocracking. Screening-type process designs and costs estimates were prepared for each case.																	

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using the economic basis specified. Results indicate that shale oil fuels refineries are more capital intensive than a comparable size petroleum refinery. No attempt was made at optimization.

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FOREWORD

This interim report details the results of Sun Tech's studies in Phase I of this contract.

Preliminary Process Analyses (Phase I) was carried out under Contract F33615-78-C-2024. The program is sponsored by the Aero Propulsion Laboratory, Air Force Wright Aeronautical Laboratory, Wright-Patterson AFB, Ohio, under Project 3048, Task 05 and work unit 01. Ms. Eva M. Conley/AFWAL/POSF, was the assigned Air Force Project Engineer.

Phase I work reported herein was performed during the period of 2 January 1979 to 1 July 1979 under the direction of Dr. Abraham Schneider, Scientific Advisor, Sun Tech, Inc. This report was released by the authors in September 1981.

Sun Tech's program manager wishes to express his appreciation to Major D. Potter, USAF, and Lt. E. N. Coppola, USAF for their help in formulating the economic assumptions upon which the financial aspects of Phase I are based and to Dr. Herbert Lander and Ms. Eva M. Conely, for their assistance in overcoming administrative and logistical problems associated with this project.

The authors wish to thank E. J. Janoski for his contributions in the area of HCl extraction and S. Fiorelli and T. J. McDowell for their assistance in estimating plant investments and operating costs.

This report is Part I of a planned number of parts of an exploratory research and development program leading to specifications for aviation turbine fuel from whole crude shale oil. Part I, Preliminary Process Analyses, evaluates three different technically feasible processing schemes proposed by Sun Tech, Inc. for converting 100,000 BPCD of raw Paraho shale oil into military turbine fuels. Other parts will follow as the different phases of the program are completed.



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TABLE OF CONTENTS

<u>SECTION</u>	<u>PAGE</u>
I SUMMARY	1
II INTRODUCTION	3
III BACKGROUND	4
IV PROCESS DETAILS	8
1. Base Case	8
2. Alternates IA-1 and IA-2	8
3. Alternates IIA-1 and IIA-2	9
4. Process Units	10
5. Material Balance Summaries	11
6. Phase I Economic Evaluation	12
V CONCLUSIONS	14
VI RECOMMENDATIONS	16
REFERENCES	17

LIST OF ILLUSTRATIONS

<u>FIGURE</u>		<u>PAGE</u>
1	Schematic Flow Diagram - Base Case	18
2	Schematic Flow Diagram - Alternate IA-1 (Max. JP-4 via HCl)	19
3	Schematic Flow Diagram - Alternate IA-2 (Max. JP-8 via HCl)	20
4	Schematic Flow Diagram - Alternate IIA-1 (Max. JP-4 via DMF)	21
5	Schematic Flow Diagram - Alternate IIA-2 (Max. JP-8 via DMF)	22
6	Simplified Flow Diagram of Shale Oil Hydrotreater and Whole Crude Distillation Section	23
7	Simplified Flow Diagram of Sulfuric Acid Contacting Plant for Processing Hydrotreated Paraho Shale Oil	24
8	Simplified Flow Diagram of Anhydrous HCl Treating Plant for Processing Hydrotreated Paraho Shale Oil	25
9	Simplified Flow Diagram of DMF Extraction Plant for Refining Gas Oil Fraction from Hydrotreated Shale Oil	26
10	Schematic Flow Diagram of Single Stage Hydrocracker with Extinction Recycle for Manufacturing Turbine Fuels from Shale Oil Raffinates	27

LIST OF TABLES

<u>TABLE</u>		<u>PAGE</u>
1	Material Balance Summary - Maximizing JP-4 from Whole Crude Shale Oil	28
2	Material Balance Summary - Maximizing JP-8 from Whole Crude Shale Oil	29
3	Basis for Developing Phase I Economics	30
4	Preliminary Estimates of Plant Investments (Maximum JP-4)	32
5	Preliminary Estimates of Plant Investments (Maximum JP-8)	33
6	Preliminary Cost Comparison for Manufacturing JP-4 from Whole Crude Shale Oil	34
7	Preliminary Cost Comparison for Manufacturing JP-8 from Whole Crude Shale Oil	36
8	Summary	38

LIST OF SYMBOLS AND ABBREVIATIONS

SYMBOLS

Bbl/SD	Barrels per Stream Day
¢/Gal	Cents per Gallon
\$/B	Dollars per Barrel
\$/CD	Dollars per Calendar Day
LT/SD	Long Tons per Stream Day
# PSD	Pounds per Stream Day
SCF H ₂ /SD	Standard Cubic Feet Hydrogen per Stream Day
ST/SD	Short Tons per Stream Day
Vol. %	Volume percent
Wt. %	Weight percent

ABBREVIATIONS

AGO	Atmospheric Gas Oil Fraction
API	American Petroleum Institute
BPCD	Barrels per Calendar Day
BPSD	Barrels per Stream Day
BR	Boiling Range
BTU's	British Thermal Units
CS	Centistokes
DCF	Discounted Cash Flow
DMF	n,n-Dimethylformamide

LIST OF SYMBOLS AND ABBREVIATIONS (Cont'd.)

FOE	Fuel Oil Equivalent
H ₂	Hydrogen Gas
HCl	Anhydrous Hydrogen Chloride
HP Sep	High Pressure Separator
H ₂ S	Hydrogen Sulfide Gas
H ₂ SO ₄	Sulfuric Acid
KV	Kinematic Viscosity
LHSV	Liquid Hourly Space Velocity
LP Sep	Low Pressure Separator
N ₂	Nitrogen
NA	Not Available
NH ₃	Ammonia Gas
O ₂	Oxygen Gas
ppm	Parts per Million by Weight
pp	Partial Pressure
psig	Pounds per Square Inch Gage Pressure
R-1	First Reactor
R-2	Second Reactor
RSO	Raw Shale Oil
S	Sulfur
TBP	True Boiling Point Distillation
TPO	Texaco Partial Oxidation Process
VGO	Vacuum Gas Oil Fraction
WTD	Weighted
WWT Plant	Waste Water Treating Plant

SECTION I

SUMMARY

This report covers work performed by Sun Tech, Inc. in Phase I of a contract with the United States Air Force. The Phase I objectives were to define and evaluate on paper the technology and potential economics (without the benefit of adequate laboratory and pilot plant data) for three different processing schemes for converting 100,000 barrels per calendar day of raw Paraho shale oil into aviation turbine fuels. Each processing scheme was developed using limited data generated by Sun Tech plus literature sources. Screening-type process design bases and cost estimates were prepared to compare various costs for maximum yields of JP-4 versus JP-8 jet fuel and to compare maximum yields of selected jet fuels versus a full slate of military fuels. Basic assumptions and conditions for developing Phase I economics were specified by the U. S. Air Force. No attempt was made in Phase I to optimize the processing configuration or product slate for maximum efficiency or minimum costs.

The Base Case consists of hydrotreating the whole crude shale oil, washing with 80% sulfuric acid to remove the basic nitrogen compounds, followed by conventional fractionation to prepare either JP-4 jet fuel or JP-8 jet fuel.

Alternate Case IA-1, JP-4 preparation and alternate Case IA-2, JP-8 preparation processing schemes consist of hydrotreating the whole crude shale oil, HCl treating the hydrotreated product to extract the basic

nitrogen compounds, followed by conventional fractionation, hydrocracking and distillation.

Alternate case IIA-1, JP-4 preparation and Alternate Case IIA-2, JP-8 preparation processing schemes consist of hydrotreating the whole crude shale oil, n,n-dimethylformamide (DMF) extraction of the heavy distillate fraction from the hydrotreated product to remove nitrogen and aromatic compounds, followed by conventional fractionation, hydrocracking and distillation.

Overall thermal efficiencies vary from 82% in the Base Case to 74-76% in the alternate cases. Yields of JP-4 and JP-8 in the Base Case are about 29 and 36 volume percent of the crude, respectively. In alternate Cases IA-1 and IIA-1, JP-4 is produced in yields of about 111 and 101 volume percent, respectively. In alternate Cases IA-2 and IIA-2, JP-8 is produced in yields of about 69 and 64 volume percent, respectively.

SECTION II

INTRODUCTION

The purpose of the Phase I program is to define and evaluate Sun Tech's concept for processing raw Paraho shale oil into high yields of military turbine fuels. Prior work to produce aircraft turbine fuels from Paraho shale oil indicated that a yield of about 70 volume percent JP-4 could be achieved.

Three different, processing schemes--a base case and two alternates are evaluated for processing 100,000 barrels per calendar day of raw Paraho shale oil.

SECTION III

BACKGROUND

In previous work sponsored by the Department of Energy and the Department of Defense, Robinson demonstrated that specification quality JP-5 could be produced from raw Paraho shale oil (1). The manufacturing processing sequence consisted of the following three steps:

- (1) Hydrotreating raw shale oil to lower its non-hydrocarbon content and to increase the hydrogen to carbon ratio,
- (2) Fractionating the hydrotreated shale oil into the desired boiling range fractions, and
- (3) Acid and clay treating to meet thermal and storage stability requirements.

A variation of this processing sequence was chosen as the Base Case. The variations consisted of the following processing steps:

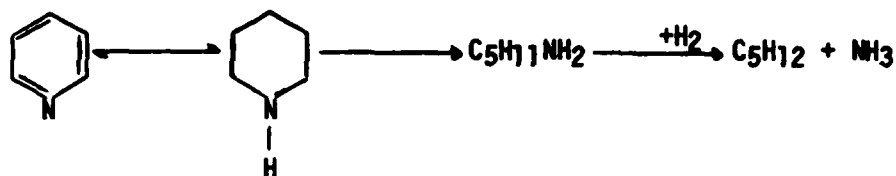
- (1) Increasing hydrotreating severity to lower the total nitrogen content of the reactor effluent to 300 ppm vs. 3000 ppm in the reference,
- (2) Washing of the hydrotreated shale oil with 80% sulfuric acid to provide product stability and,
- (3) Final distillation into the desired product boiling ranges.

Sun Tech's processing concept is based on in-house experience. Initially raw shale oil is hydrotreated, as in the Base Case, then followed by distillation. The heavy fraction is extracted to further reduce its nitrogen content. The nitrogen content of the raffinate phase is now reduced sufficiently for charging directly into a hydrocracker. The extract

phase, which is rich in heteroatoms, is then used to manufacture hydrogen by partial oxidation. Through the use of moderate hydrogenation severity, hydrogen is conserved.

Whole crude shale oil typically contains approximately 2 weight percent of nitrogen of which 50 to 70 weight percent is in the basic form. The major portion of the nitrogen is present in five and six member rings which are unsaturated and polycyclic in nature. Before crude shale oil can be processed into transportation fuels using conventional petroleum catalytic conversion processes, the nitrogen level must be significantly reduced or essentially eliminated to avoid poisoning the acid function of catalysts. Removal of this nitrogen can be accomplished by hydrodenitrogenation as described by Cocchetto and Satterfield (2). Nitrogen, for the most part, is present as heterocyclic compounds. It is reduced to ammonia and removed as such or the heterocyclic compounds are saturated to basic nitrogen structures. All compounds are then extracted with a mineral acid, such as HCl, to form an amine hydrochloride. Most of the amine hydrochlorides are insoluble in hydrocarbons and form a dense and viscous liquid phase which separates from the hydrocarbons in the system.

It has been reported by Dinneen (3) that fractions of Colorado shale oil contain pyridines, indoles, quinolines, tetrahydroquinolines and more complex structures. Hydrodenitrogenation of these compounds as described by McIlvried et al., generally proceeds by first saturating the nitrogen bearing ring, breaking the carbon-nitrogen bond and then removing the nitrogen from the amine as ammonia (4).



It can be seen from the above model equation that hydrotreating converts the unsaturated heterocyclic compound (pyridene) to the saturated structure (piperidine) or the aliphatic amylamine.

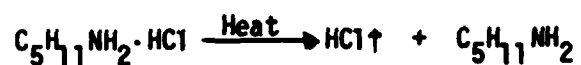
The addition of anhydrous HCl can form the hydrochloride salt of either one or both of the nitrogen containing compounds.



It can be seen that hydrogen would be conserved by not proceeding all the way to form ammonia.

Examination of the amine hydrochloride extract showed the presence of both basic and neutral nitrogen. The ratio of basic nitrogen to total nitrogen was 0.775. The ratio suggests a bonus of an additional 30% removal of nitrogen per chlorine atom indicating that some molecules contain both basic and neutral nitrogen.

Decomposition of the extract releases HCl and the recovered extract can be used for manufacturing hydrogen by partial oxidation. This process can be represented by the following equations:



Downstream processing converts the CO to H₂ and CO₂ via the water-gas shift reaction.

The processing sequence which uses anhydrous HCl extraction is Alternate IA of this report. Alternate IIA uses a selective solvent, such as dimethylformamide, to extract basic nitrogen compounds plus some aromatics.

SECTION IV

PROCESS DETAILS

1. Base Case

The Base Case is shown schematically in Figure 1. This processing scheme calls for hydrotreating raw Paraho shale oil to reduce the total nitrogen content in the liquid effluent to 300 ppm. The hydrotreated product is then sent to a sulfuric acid contacting plant to further reduce the nitrogen level to less than 50 ppm. The product from the acid contacting plant is distilled to yield either 29 volume percent JP-4 jet fuel or 36 volume percent JP-8 jet fuel, based on raw shale oil charged to the hydrotreater. Other products produced include gasoline blendstock, #2 diesel fuel, #4D diesel or #4 fuel oil, and an 850°F+ bottoms residual fuel that is used for hydrogen generation in a Texaco partial oxidation process plant.

2. Alternates IA-1 and IA-2

Alternate IA-1 is shown schematically in Figure 2. In this alternate, the total nitrogen content of the hydrotreated Paraho shale oil is 2000 ppm. The hydrotreated product is fractionated in atmospheric and vacuum distillation units. The 180-450°F boiling material goes to a naphtha hydrotreater to clean up the light distillate from the atmospheric distillation to meet JP-4 product specifications. The 450-1000°F boiling gas oil is sent to an HCl treating plant which yields a nitrogen-rich

extract phase and a reduced nitrogen content raffinate phase. The raffinate is hydrocracked to maximize the yield of aviation turbine fuel; in this case 100 percent JP-4 jet fuel. Hydrocracking yields and operating conditions were estimated from previous DOE sponsored work (5) and in-house data. The recovered extract is sent to a Texaco partial oxidation plant to generate hydrogen.

Figure 3 is a schematic flow diagram for Alternate IA-2. This alternate also incorporates hydrotreating, HCl treating, and hydrocracking in the processing scheme but the distillation cut points are adjusted to maximize JP-8 jet fuel instead of JP-4. A C_4 -300°F gasoline blendstock is produced as a co-product.

3. Alternates IIA-1 and IIA-2

Alternate IIA-1, shown in Figure 4, is similar to Alternate IA-1, except that DMF extraction is employed instead of HCl treating. The amine extract is used to generate hydrogen in a Texaco Partial Oxidation plant. The raffinate from the extraction unit is hydrocracked to maximize JP-4 jet fuel.

Alternate IIA-2, shown in Figure 5, also employs DMF extraction. However, the distillation cut points are adjusted to maximize JP-8 jet fuel. A C_4 -300°F boiling range gasoline blendstock is also obtained.

4. Process Units

For the Base and Alternate Cases, a raw shale oil hydrotreater is used to reduce the high nitrogen content present in raw Paraho shale oil. Figure 6 presents a simplified flow diagram of a raw shale oil hydrotreater and whole crude distillation section. Guard reactors are used to remove arsenic and iron, as well as to saturate olefins. The distillation section is used in all cases. The cut points are adjusted to fit the specific alternate. The vacuum still is used to obtain a 1000°F end point gas oil. The 1000°F+ vacuum still bottoms is not used in subsequent extraction steps, since there was concern that its inclusion might lead to the formation of emulsions.

Figure 7 presents a simplified flow diagram of a sulfuric acid contacting plant for processing hydrotreated Paraho shale oil. This type of plant is employed in the Base Case only. An 80% sulfuric acid stream is mixed with hydrotreated shale oil at 5 pounds of acid per barrel of hydro-treated shale oil. The raffinate leaving the acid settler is washed with water before being sent to fractionation. The heavy extract phase is neutralized with caustic or lime solution before leaving the plant.

A simplified flow diagram of an anhydrous HCl treating plant is shown in Figure 8. Vacuum dried atmospheric and vacuum gas oils are combined and reacted with anhydrous HCl in a stirred reactor. The HCl raffinate is separated from the nitrogen rich extract phase in the adduct settler. The HCl raffinate is then neutralized with a 15% caustic solution before being sent to the hydrocracker. The HCl extract is removed from the

adduct settler and thermally decomposed to recover anhydrous HCl which is recycled to the stirred reactor. The decomposed extract is passed through a lime treater before being used for generating hydrogen by partial oxidation. The HCl treating plant is used in Alternates IA-1 and IA-2.

DMF extraction is used in Alternates IIA-1 and IIA-2. A simplified flow diagram of the DMF extraction plant is shown in Figure 9. DMF and a wide boiling gas oil fraction are fed counter-currently into the extraction column. The reduced nitrogen content raffinate phase is taken overhead and is stripped of DMF before being sent to the hydrocracker. The nitrogen rich extract phase leaves the bottom of the extraction tower and is stripped of DMF and dissolved raffinate. The extract is then sent to the partial oxidation plant for hydrogen generation.

Raffinate hydrocracking is employed in all alternate cases to maximize the yields of jet fuels. A schematic flow diagram of a single stage hydrocracker with extinction recycle is shown in Figure 10. The hydro-treating reactor is used to clean up the raffinate feed before it enters the main hydrocracking reactor where most of the hydrocracking takes place. The cut points taken off the fractionator are adjusted to fit a specific alternate.

5. Material Balance Summaries

Material balance summaries for maximizing JP-4 jet fuel from whole crude shale oil are presented in Table 1. Refinery fuel, electricity, and

steam were converted to a fuel oil equivalent (FOE) basis. Based on total energy input to the refinery, 26.8 volume percent JP-4 is produced in the Base Case, 91.3 volume percent JP-4 in Alternate IA-1 using HCl treating, and 88.2 volume percent JP-4 in Alternate IIA-1 using DMF extraction.

Table 2 presents material balance summaries for maximizing JP-8. Using a basis of total energy input to the refinery, 32.6 volume percent JP-8 is produced in the Base Case, 57.1 volume percent JP-8 in Alternate IA-2 using HCl treating, and 56.0 volume percent JP-8 in Alternate IIA-2 using DMF extraction.

6. Phase I Economic Evaluation

Guidelines for developing Phase I economics are given in Table 3. A September 1978 cost base is used. Crude shale oil is valued at \$16/Bbl and all product fuels are equally valued at \$21/Bbl. These prices were used for calculating interest charges for working capital. Preliminary estimates of plant capacities and investments are presented for the Base Case and for maximizing JP-4 in Table 4 and for maximizing JP-8 in Table 5. The main hydrotreater and the Texaco Partial Oxidation plants account for the majority of the processing facility costs. Total capital investments range from \$582.0 million for the Base Case to \$834.0 million for Alternate IIA-1. Preliminary product costs for manufacturing JP-4 from whole crude shale oil are given in Table 6 as: \$0.59/gallon of product for the Base Case, \$0.61/gallon for Alternate IA-1 (HCl), and \$0.67/gallon for Alternate IIA-1 (DMF). Optimization studies were not

performed for this evaluation. Preliminary product costs for manufacturing JP-8 from whole crude shale oil are given in Table 7 as: \$0.59/gallon for the Base Case, \$0.61/gallon for Alternate IA-2 (HCl), and \$0.66/gallon for Alternate IIA-2 (DMF). Results of the various processing routes are summarized in Table 8. Plant investments ranged from \$5820/MB of raw shale oil feed for the Base Case to \$8340/MB of raw shale oil for Alternate IIA-1 using DMF extraction.

SECTION V

CONCLUSIONS

1. Preliminary economics show that in the Base Case where a complete range of transportation fuels is produced, the estimated total investment (Sept. 1978 midwest location) for a shale oil refinery is 582×10^6 vs. about 300×10^6 for a conventional petroleum fuels refinery. This suggests that shale oil refineries are considerably more expensive than a corresponding petroleum fuels refinery of the same size. When JP-4 fuel is maximized, capital costs increase to about 790×10^6 in the case of the HCl Extraction alternates and up to about 830×10^6 for the DMF solvent extraction alternates.
2. Raw shale oil hydrotreaters are the most expensive refinery units in the processing schemes with hydrogen manufacturing facilities and the catalytic hydrocracker following in that order.
3. Total manufacturing costs vary between 59¢ to 67¢ per gallon (\$25 to \$28 per barrel) of product with raw shale oil feed at the specified cost of \$16 per barrel. Maximizing the yield of a specific product increases both capital investment and processing costs.
4. HCl treating of hydrotreated shale oil provides an effective method for removing nitrogen compounds from the hydrotreated shale oil, while conserving hydrogen.

5. DMF extraction of hydrotreated shale oil is also an effective method for removing nitrogen compounds from the hydrotreated shale oil, but it is more capital intensive than HCl extraction.
6. A minimum refinery thermal efficiency of 70% should be attained using Sun Tech's proposed processing schemes.

SECTION VI

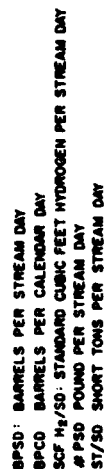
RECOMMENDATIONS

It is recommended that:

1. Data needed to optimize processing schemes and balance product slates be obtained in the pilot plant.
2. Trade-off studies be undertaken to evaluate the relative merits of HCl treating versus DMF extraction of hydrotreated shale oil.
3. Operating severity in the raw shale oil hydrotreater required to produce sufficient extract to meet refinery hydrogen requirements be defined.
4. Catalyst life studies be initiated for the raw shale oil hydrotreater and gas oil hydrocracker catalyst systems.
5. The HCl and DMF extracts be evaluated as potential feedstocks to the Texaco Partial Oxidation plant for hydrogen generation.

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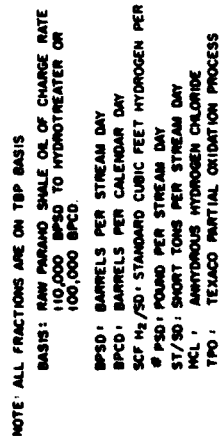
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BPSD : BARRELS PER STREAM DAY
 BPCD : BARRELS PER CALENDAR DAY
 SCF H₂/SD : STANDARD CUBIC FEET HYDROGEN PER STREAM DAY
 # PSD : POUND PER STREAM DAY
 ST/SD : SHORT TONS PER STREAM DAY
 MCL : AMYOTROUS HYDROGEN CHLORIDE
 TPO : TEXACO PARTIAL OXIDATION PROCESS

HYDROTREATING, HCL TREAT, HYDROCRACKING AND
DISTILLATION FOR TRANSPORTATION FUELS



BASIS: RAW PARADO SHALE ON OF CHARGE RATE

110,000 BPSD TO HYDROTREATER OR 100,000 BPSD

116,000 SF OF NEW HIGH-RISE

NAME: N,N-DIMETHYLFORMAMIDE

WPSD: BARNELS PER STREAM DAY

SPCD: BARRELS PER CALENDAR DAYSCF H₂/SD: STANDARD CUBIC FEET HYDROGEN PER STANDARD CUBIC FOOT OF DRY GAS AT 14.7 PSIA AND 60°F.

④ PPD: POUND PER STREAM DAY

ST/SD: SHORT TONS PER STREAM DAY

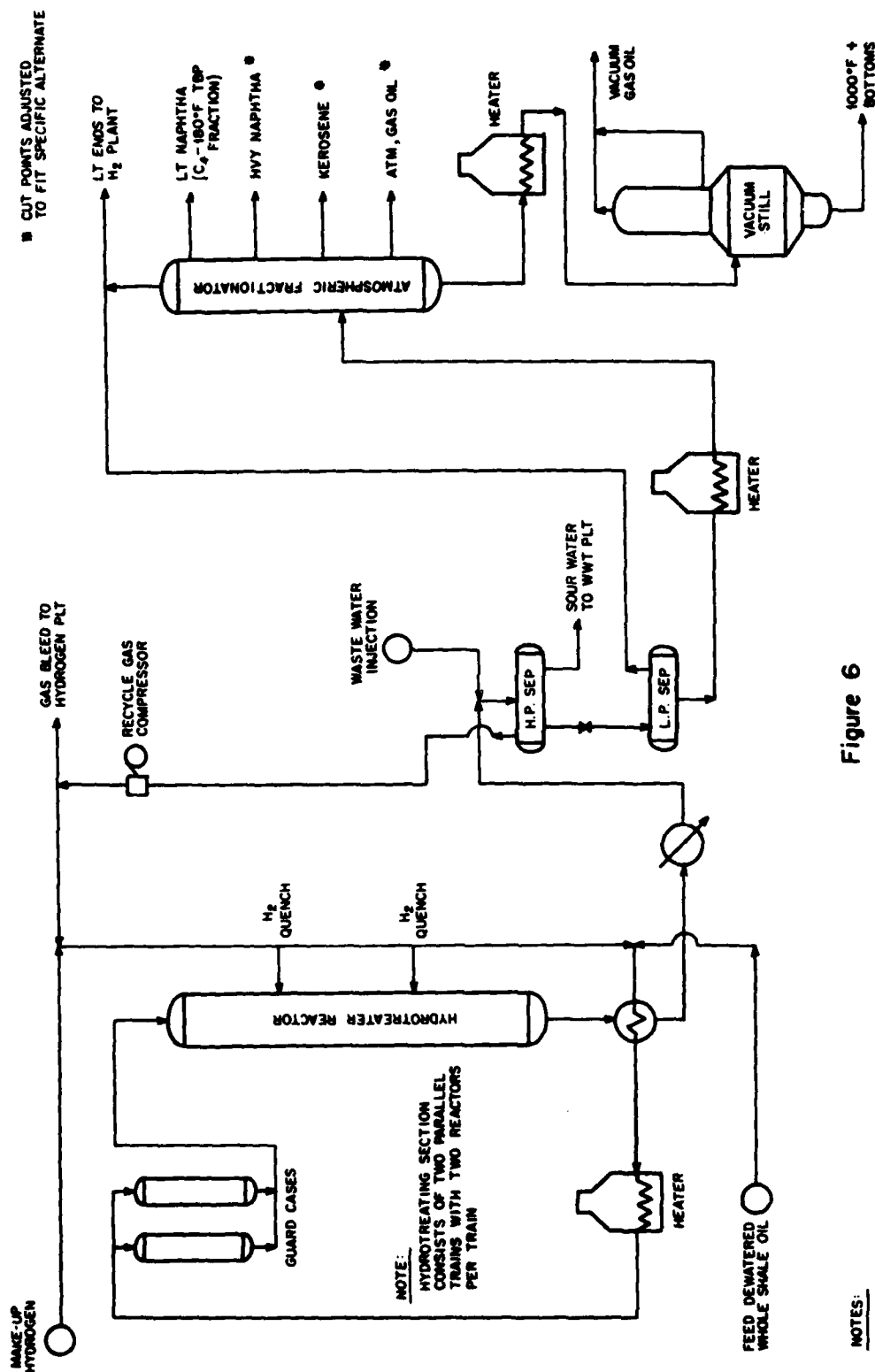
TPD: TEXACO PARTIAL OXIDATION PROCESS

Fig. 4 REFINING RAW PARANO SHALE OIL

SCHEMATIC FLOW DIAGRAM - ALTERNATE II A-1 (Mon JP-4)



Fig. 5 REFINING RAW PARAHIO SHALE OIL



HER/JCC
5/29/79

Figure 6
SIMPLIFIED FLOW DIAGRAM OF
SHALE OIL HYDROTREATER AND
WHOLE CRUDE DISTILLATION SECTION

NOTES:
H.P. SEP: HIGH PRESSURE SEPARATOR
L.P. SEP: LOW PRESSURE SEPARATOR
TBP: TRUE BOILING POINT
WWT: WASTE WATER TREATING PLT

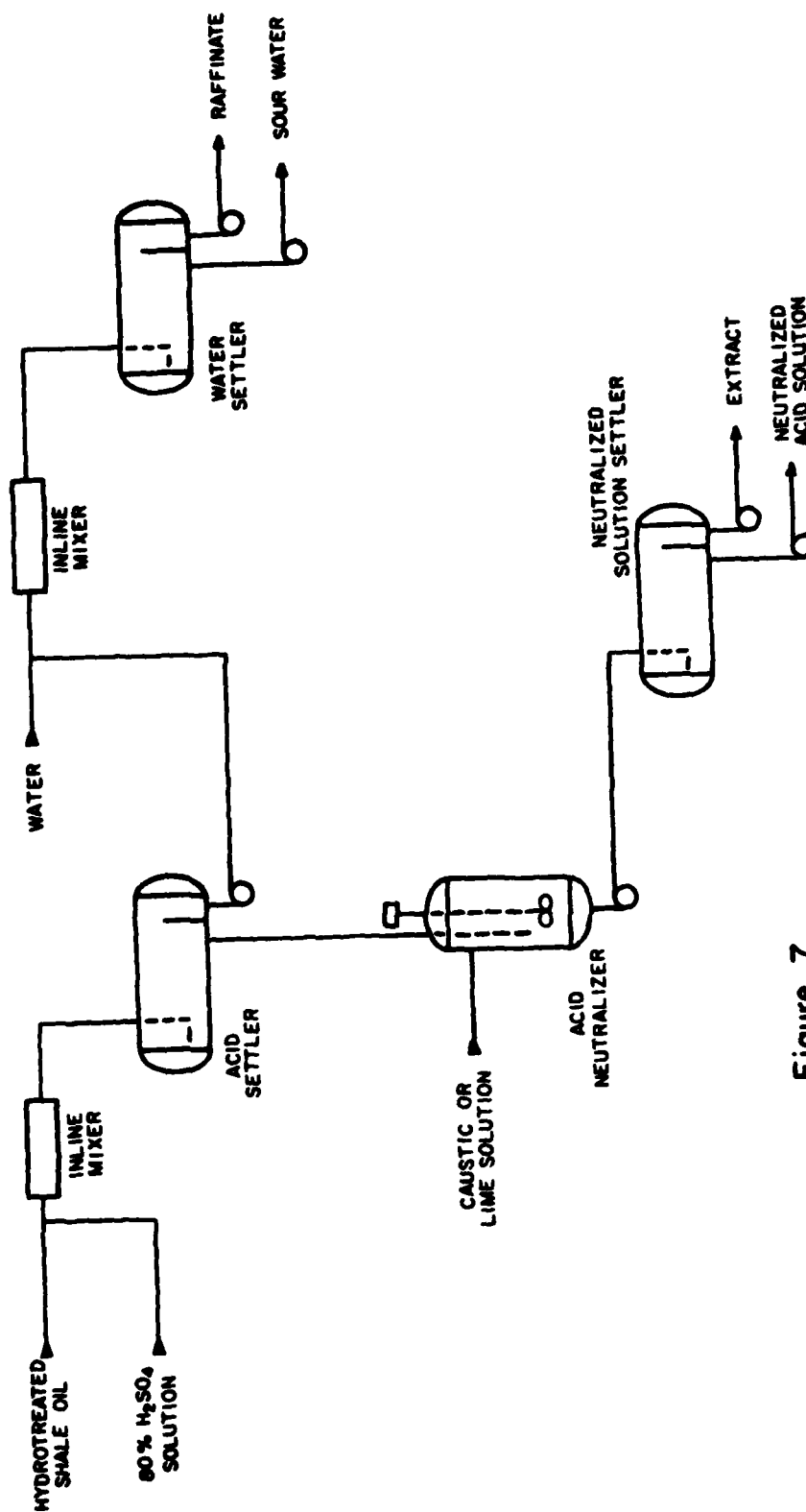


Figure 7
BASE CASE

SIMPLIFIED FLOW DIAGRAM OF SULFURIC
ACID CONTACTING PLANT FOR PROCESSING
HYDROTREATED PARAHO SHALE OIL

SF/JCC
5/11/79

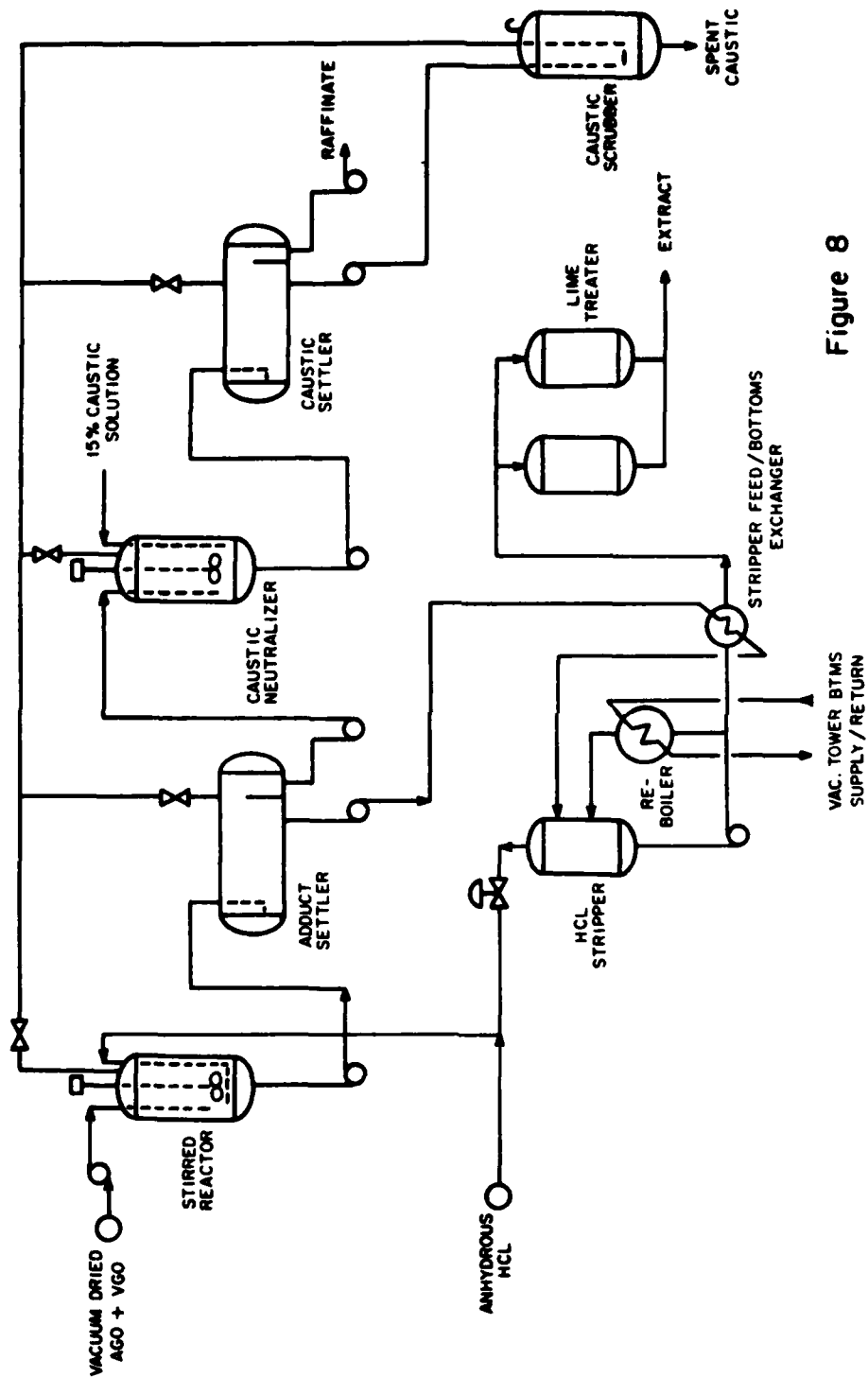


Figure 8

ALTERNATE 1A-1&2

SIMPLIFIED FLOW DIAGRAM OF ANHYDROUS HCL TREATING PLANT FOR PROCESSING HYDROTREATED PARAHO SHALE OIL

SF/JCC
5/11/75

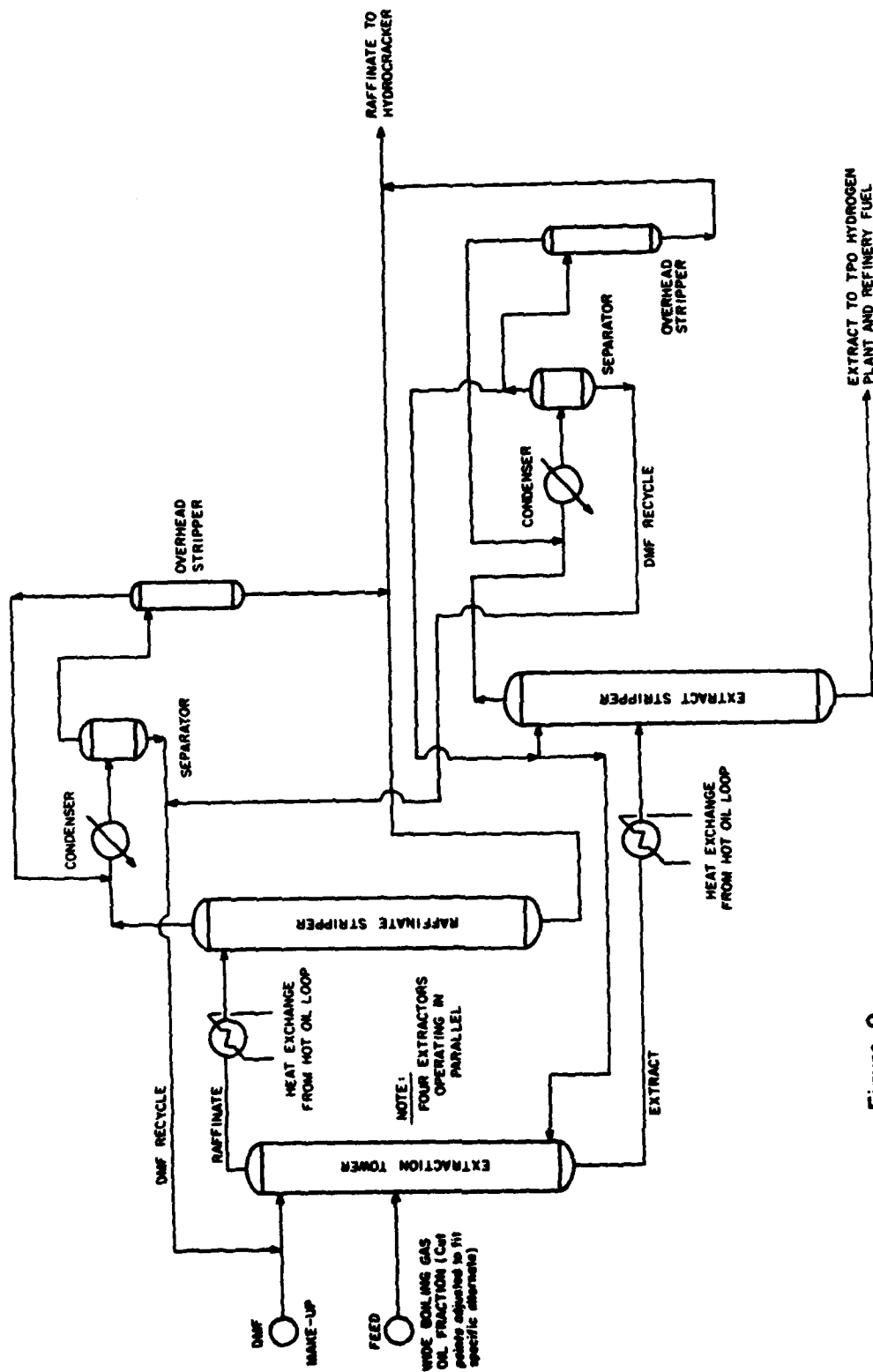


Figure 9
SIMPLIFIED FLOW DIAGRAM OF DMF
EXTRACTION PLANT FOR REFINING GAS
OIL FRACTION FROM HYDROTREATED
WHOLE SHALE OIL

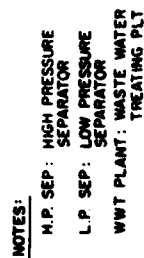


Figure 10

**SCHEMATIC FLOW DIAGRAM OF SINGLE STAGE HYDRO -
CRACKER WITH EXTINCTION RECYCLE FOR MANUFACTURING
TURBINE FUELS FROM SHALE OIL RAFFINATES**

HER/JCC
5/29/79

TABLE 1

MATERIAL BALANCE SUMMARY - MAXIMIZING JP-4 FROM WHOLE CRUDE SHALE OIL

	<u>BASE</u>	<u>ALT. IA-1 (HCl)</u>	<u>ALT. IIA-1 (DMF EXT.)</u>
BASIS: 110,000 BPSD FEED RATE			
Net Products, BPSD (TBP Cuts)			
C4-300°F Gasoline Blend Stock			
C4-450°F JP-4	32,268	122,276	110,637
Distillate Fuel (450-840°F)	75,032		
TOTAL	107,300	122,276	110,637
Other Products, STSD			
Ammonia	464	439	432
Sulfur	119	120	119
Liquid Fuel Products Yields			
Total Products as Vol.% Feed	97.6	111.2	100.6
JP-4 as Vol.% Feed	26.3	111.2	100.6
Total Refinery Input (Crude, Fuel & Utilities Converted to FOE BPSD)	120,393	133,911	125,478
Total Products as Vol.% Refinery Input	89.1	91.3	88.2
JP-4	26.8	91.3	88.2
Overall Refinery Thermal Energy Efficiency, %	82	76	74

TABLE 2

MATERIAL BALANCE SUMMARY - MAXIMIZING JP-8 FROM WHOLE CRUDE SHALE OIL

BASIS: 110,000 BPSD FEED RATE

Net Products, BPSD (TBP Cuts)	<u>BASE</u>	<u>ALT. IA-2 (HC1)</u>	<u>ALT. IIA-2 (DMF EXT.)</u>
C4-300°F Gasoline Blend Stock	12,467	44,279	40,317
300-535°F JP-8	39,223	75,682	70,347
Distillate Fuel (535-850°F)	<u>55,610</u>		
TOTAL	107,300	119,961	110,664
Other Products, STSD			
Ammonia	464	439	432
Sulfur	119	120	119
Liquid Fuel Products Yields			
Total Products as Vol.% Feed	97.6	109.1	100.6
JP-8 as Vol.% Feed	35.7	68.8	64.0
Total Refinery Input (Crude, Fuel & Utilities Converted to FOE BPSD)	120,393	132,461	125,705
Total Products as Vol.% Refinery Input	89.1	90.6	88.0
JP-8	32.6	57.1	56.0
Overall Refinery Thermal Energy Efficiency, %	82	76	74

TABLE 3
BASIS FOR DEVELOPING PHASE I ECONOMICS

GENERAL

1. Capital and operating costs estimates for each refining scheme based on: a) In-house data. B) Literature sources.
2. Processing schemes not optimized.
3. No allowances for transporting raw shale oil to refinery or finished products from refinery are included.

PLANT COSTS

Location:	Mid West
Type:	Grass Roots (adjacent to existing refinery)
Cost Base:	September 1978
Feed:	Whole raw shale oil (Paraho)
Tankage:	30 days storage capacity for raw shale oil and products
Crude Rate:	100,000 BPCD
Utilities:	Available at plant site at costs specified:
	Electricity
	Steam
	Fuel
	Cooling Water

CAPITAL RECOVERY

Equity		Debt
Financing:	100%	Financing: 10% annual interest rate
Return on Investment:	15% discounted cash flow after taxes	
Plant Life:	16 years with zero salvage value	
Depreciation:	13 years sum of years digits	
Federal Plus State Tax Rate:	50%	
Investment Tax Credit:	10% of capital investment	
Working Capital:	30 days inventory of crude @ \$16/Bbl and 30 days product @ 21/Bbl	

TABLE 3 (Continued)
BASIS FOR DEVELOPING PAHSE I ECONOMICS

OPERATING COSTS

Direct Labor

Operators:	\$9.50/hr.	
Helpers:	\$8.50/hr	wtd. avg. \$8.80/hr
Supervision:	25% of labor costs	

NOTE: 4.2 shift positions plus 10% relief required for continuous operation.

Overhead: 100% direct labor (fringe benefits, overhead, general and administrative and control laboratory costs).

Maintenance, Local Taxes and Insurance: 4.5% estimated erected plant costs

Start-up Costs: 5% estimated erected plant costs

Crude Shale Oil: \$16.00/Bbl. at plant site

Product Values: All fuels equal (\$21.00/Bbl. for calculating working capital)

By-Products: Amomonía - \$120/short ton
 Sulfur - \$53/long ton

UTILITIES

Fuel: \$2.50 per 10⁶ net BTU's
 (FOE bbl. @ 6.0 X 10⁶ net BTU's)

Electricity: 3.5¢ per kw hour

Cooling Water: 3¢ per 1,000 gallons

Saturated Steam: 600 psig @ \$3.90/1,000 lbs.
 250 psig @ \$3.30/1,000 lbs.
 50 psig @ \$2.50/1,000 lbs.

Catalyst and Chemicals: At cost

Royalties: Running basis

TABLE 4

PRELIMINARY ESTIMATES OF PLANT INVESTMENTS (JP-4 PRODUCTION)

CASE	BASE		ALTERNATE IA-1 (HCl)		ALTERNATE IIA-1 (DMF EXT)	
	CAPACITY	\$ X 10 ⁶	CAPACITY	\$ X 10 ⁶	CAPACITY	\$ X 10 ⁶
H ₂ (Partial Oxidation), MMSCF/D	186	107.4	187	107.8	181	105.8
H ₂ (Steam-Methane), MMSCF/D	86	28.8	143	35.0	137	34.2
Sulfur Recovery, ST/SD	119	11.5	120	11.5	119	11.5
Waste Water Treating, ST/SD NH ₃	464	22.3	439	21.6	238	21.6
Hydrotreater & H ₂ S Rec., MBPSD	110	160.0	110	160.0	110	160.0
Atm. & Vac. Distn. MBPSD	118	36.8	118	44.0	118	44.0
Dist. Hydrotreater, MBPSD			25.2	30.0	25.2	30.0
Hydrocracker, MBPSD	120	0.5	80.7	98.1	71.7	91.6
Acid Wash, MBPSD					82.9	41.6
DMF Extraction, MBPSD			82.9	2.3		540.3
HCl Treater, MBPSD				510.3		
Sub Total		367.3				
Tankage, MM Bbls.	6.9	49.4	7.2	51.5	7.0	50.1
Total On-Sites		416.7		561.8		590.4
Off-Sites						
(45% On-Sites Minus Tankage)		165.3		230.2		243.6
Total Capital Cost		582.0		792.0		834.0

TABLE 5

PRELIMINARY ESTIMATES OF PLANT INVESTMENTS (JP-8 PRODUCTION)

CASE	BASE		ALTERNATE IA-2 (HC1)		ALTERNATE IIA-2 (DMF EXT)	
	CAPACITY	\$ X 10 ⁶	CAPACITY	\$ X 10 ⁶	CAPACITY	\$ X 10 ⁶
H ₂ (Partial Oxidation), MMSCF/D	186	107.4	180	105.5	177	104.0
H ₂ (Steam-Methane), MMSCF/D	86	28.8	136	33.9	129	33.1
Sulfur Recovery, ST/SD	119	11.5	120	11.5	119	11.5
Waste Water Treating, ST/SD NH ₃	464	22.3	439	21.6	438	21.6
Hydrotreater & H ₂ S Rec., MBPSD	110	160.0	110	160.0	110	160.0
Atm. & Vac. Distn. MBPSD	118	36.8	118	44.0	118	44.0
Dist. Hydrotreater, MBPSD			38.3	38.0	38.0	38.0
Hydrocracker, MBPSD			67.7	88.3	60.4	82.4
Acid Wash, MBPSD	120	0.5				
DMF Extraction, MBPSD					69.8	37.9
HC1 Treater, MBPSD			69.8	2.3		
Sub Total		367.3		505.1		532.5
Tankage, MM Bbls.	6.9	49.4	7.1	50.3	7.1	50.6
Total On-Sites		416.7		555.4		583.1
Off-Sites						
(45% On-Sites Minus Tankage)		165.3		227.6		239.9
Total Capital Cost		582.0		783.0		823.0

TABLE 6

PRELIMINARY COST COMPARISON FOR MANUFACTURING JP-4 FROM WHOLE CRUDE SHALE OIL

Basis: 100,000 BPCD Crude to Hydrotreater

	COSTS IN DOLLARS PER CALENDAR DAY		
	BASE	ALT. 1A-1 (HCT)	ALT. 11A-1 (DMF EXT.)
Direct Labor	8,976	12,514	13,213
Purchased Utilities	177,400	320,444	329,308
Catalysts, Chemicals & Royalties	87,960	70,940	66,240
Overhead @ 100% Direct Labor	8,976	12,514	13,213
Maint. Local Taxes & Insurance	51,374	69,263	72,789
Depreciation (Avg. Over 13 years)	122,655	166,913	175,764
Total Operating Expenses	457,341	652,588	670,527

TABLE 6 (Continued)

PRELIMINARY COST COMPARISON FOR MANUFACTURING JP-4 FROM WHOLE CRUDE SHALE OIL

	COSTS IN DOLLARS PER CALENDAR DAY		
	BASE	ALT. 1A-1 (HCl)	ALT. 11A-1 (DMF EXT.)
Total Investment, \$ x 10 ⁶			
Plant	582.0	792.0	834.0
Catalysts, Etc.	9.9	16.2	17.5
Working Capital	112.1	120.8	113.0
TOTAL	704.0	929.0	964.5
JP-4 Yield, BPCD	29,364	111,078	100,680
TOTAL MANUFACTURING COSTS, \$/CD	893,465	1,239,246	1,284,691
Less Credit for NH ₃ & Sulfur, \$/CD	837,642	1,186,139	1,232,393
Liquid Products (Fuels), BPCD	97,643	111,078	100,680
Mfg. Cost, \$/B Product	8.58	10.68	12.24
Adjusted Crude Cost, \$/B	16.40	14.77	15.89
TOTAL FUEL PRODUCT COST \$/B (¢/GAL)	24.98 (59)	25.45 (61)	28.13 (67)

TABLE 7

PRELIMINARY COST COMPARISON FOR MANUFACTURING JP-8 FROM WHOLE CRUDE SHALE OIL

Basis: 100,000 BPCD Crude to Hydrotreater

	COSTS IN DOLLARS PER CALENDAR DAY		
	<u>BASE</u>	<u>ALT. 1A-2 (HCT)</u>	<u>ALT. 1YA-2 (DMF EXT.)</u>
Direct Labor	8,976	12,514	13,213
Purchased Utilities	177,400	303,416	311,030
Catalysts, Chemicals & Royalties	87,960	66,554	62,474
Overhead @ 100% Direct Labor	8,976	12,514	13,213
Maint. Local Taxes & Insurance	51,374	68,474	71,889
Depreciation (Avg. Over 13 years)	122,655	168,156	173,445
Total Operating Expenses	457,341	631,628	645,264

TABLE 7 (Continued)
PRELIMINARY COST COMPARISON FOR MANUFACTURING JP-8 FROM WHOLE CRUDE SHALE OIL

	COSTS IN DOLLARS PER CALENDAR DAY		
	BASE	ALT. 1A-2 (HCT)	ALT. 11A-2 (DMF EXT.)
Total Investment, \$ X 10 ⁶			
Plant	582.0	783.0	823.0
Catalysts, Etc.	9.9	14.9	16.1
Working Capital	112.1	119.4	113.0
TOTAL	704.0	917.3	952.1
JP-8 Yield, BPCD	35,692	68,871	64,016
TOTAL MANUFACTURING COSTS, \$/CD	893,465	1,210,847	1,250,943
Less Credit for NH ₃ & Sulfur, \$/CD	837,642	1,157,740	1,198,645
Liquid Products (Fuels), BPCD	97,643	109,165	100,704
Mfg. Cost, \$/B Product	8.58	10.61	11.90
Adjusted Crude Cost, \$/B	16.40	14.99	15.89
TOTAL FUEL PRODUCT COST \$/B (¢/GAL)	24.98 (59)	25.60 (61)	27.79 (66)

TABLE 8
S U M M A R Y

BASIS: 100,000 BPCD WHOLE RAW SHALE OIL

JP-4 PRODUCTION

<u>Processing Route</u>	<u>Hydrotreat Acid Wash</u>	<u>Via HCl Extraction</u>	<u>Via DMF Extraction</u>
Jet Fuel Yield, Vol.% Based on Crude	29.3	111.2	100.6
Plant Investment, \$/MB Crude	5820	7920	8340
Total Cost, Including Crude, \$/B ¢/Gal	24.98 59	25.45 61	28.13 67

JP-8 PRODUCTION

Jet Fuel Yield, Vol.% Based on Crude	35.7	68.8	64.0
Plant Investment, \$/MB Crude	5820	7830	8230
Total Cost, Including Crude, \$/B ¢/Gal	24.98 59	25.60 61	27.79 66

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